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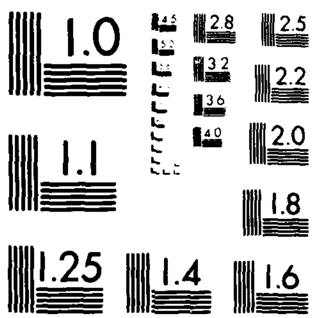
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TECHNICAL REPORT 8007 LEVEL II

ROTATING BIOLOGICAL CONTACTOR PROCESS FOR SECONDARY TREATMENT AND RECARBONATION FOLLOWING LOW-LEVEL LIME ADDITION FOR PHOSPHORUS REMOVAL

CHARLES I. NOSS

ROY D. MILLER, MAJ, MSC

U S ARMY MEDICAL BIOENGINEERING RESEARCH & DEVELOPMENT LABORATORY

Fort Detrick

Frederick, Maryland 21701

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U.S. ARMY MEDICAL RESEARCH and DEVELOPMENT COMMAND

FORT DETRICK

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Lime addition to raw wastewater can significantly aid a rotating biological contactor (RBC) plant in producing effluents in compliance with National Pollutant Discharge Elimination System (NPDES) permit limitations for biochemical oxygen demand (BOD_5), suspended solids, and phosphosurs. Low-level lime addition does not require recarbonation and does not produce the sludges typical of high pH lime treatment schemes.

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Abstract (cont.)

Biological treatment and recarbonation are usually recognized as separate processes within the water and wastewater industry. Recarbonation has traditionally employed carbon dioxide gas generated by burning a fuel such as coke, oil, or gas. The use of microorganisms for biological recarbonation, in which carbon dioxide gas is produced by the microorganisms as organic matter is oxidized, has become accepted practice for the activated sludge process. Biological recarbonation has not been previously recommended as a capability of the RBC process. The significance of using the RBC process for secondary treatment and recarbonation is that effective reductions of BOD_5, ammonia-nitrogen, and phosphorus can all occur within this system. Studies indicated that the RBC process for secondary treatment and recarbonation of wastewater is compatible with the low-level lime addition technique for phosphorus removal. Thereby, expensive recarbonation requirements and the energy-intensive activated sludge process are both avoided.

The pilot RBC process provided effective BOD_5 removal when subjected to an influent pH of 9.5 for hydraulic loading rates of 2.0, 3.0, and 4.0 gpd/sq ft. Under conditions where the wastewater influent was split between RBC stages 1 and 3, comparable rates of nutrient removal as well as overall recarbonation were observed. In addition to the removal of phosphorus, lime pretreatment reduced the organic loading on the RBC process and allowed for recarbonation by microbial populations, which produced carbon dioxide, thereby forming the carbonate alkalinity necessary for nitrification after the initial BOD_5 has been removed. The resultant pH after recarbonation is also in the optimal range for nitrification. Nitrification is further enhanced because the availability of the RBC media surface area for nitrifying organisms increases as the surface area requirements for heterotrophic organisms decline with decreased BOD_5 loading.

The RBC pilot unit consists of four compartments in series. The 0.5-meter plastic disks provide 250 sq ft of surface area for microbial attachment. The disk was rotated through the liquor at 13 rpm with 40 percent of the fixed film submerged at any point. The RBC was operated at hydraulic loading rates ranging from 2.0 to 4.0 gpd/sq ft. The RBC/recarbonation pilot studies used domestic wastewater. A constant flow of wastewater was fed into a rapid mix tank where the pH was adjusted to 9.5 by the addition of lime. Then, flocculation and primary clarification processes removed lime sludge containing the precipitated phosphorus compounds. The primary effluent entering the RBC ranged in pH values from 9.0 to 10.0. Phosphorus precipitation, nutrient levels entering the RBC, biological treatment efficiency, and biological recarbonation were all monitored.

ACKNOWLEDGMENTS

The authors wish to extend special thanks to Kenneth A. Bartgis, Engineering Technician; SSG Felix E. Legaspi, Jr., Engineering Assistant; Charles F. Harrison, Physical Science Technician; John Roach, Physical Science Technician; and Ralph Chyrek, Engineering Technician, for their technical assistance for the duration of the project.

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INTRODUCTION

Wastewaters contribute heavily to accelerated eutrophication problems in the nation's surface waters. Phosphorus, a growth-limiting nutrient for algae and aquatic plants, is normally present in minute quantities. However, significant amounts of phosphoric compounds in these wastewaters result in the overfertilization of receiving water bodies. Wastewater effluent standards have, therefore, been imposed in an attempt to limit the phosphorus concentration relative to that which exists at the point of discharge.

Increased restrictions on water uses due to quality deterioration are attributed to the availability of critical nutrients that stimulate excessive algae and plant growth. The identification of phosphorus as such a growth-limiting nutrient, plus its high concentrations in wastewaters, has resulted in wastewater discharge limitations for phosphorus. Discharge limitations are embodied in the National Pollutant Discharge Elimination System (NPDES) permits, which apply to all categories of wastewater. Department of the Army installations must apply for and receive discharge permits for all wastewater discharges. In many cases, existing NPDES permits impose phosphorus limitations on Army-produced wastewaters.

Like phosphorus, ammonia-nitrogen is also a growth-limiting nutrient for aquatic biota, but the nitrogen source may be more difficult to control. Even though much of the organic nitrogen present in surface waters was derived from surface runoff and nitrogen-fixing algae, the accelerated eutrophication of receiving water bodies can be checked by limiting ammonia-nitrogen concentrations in wastewater effluents. The addition of ammonia-laden wastewater effluents to receiving streams has numerous detrimental effects on existing aquatic life. Ammonia-nitrogen exerts an oxygen demand, thereby depleting the dissolved oxygen levels because oxidation to nitrite and nitrate occurs. Ammonia-nitrogen 0.3 mg/L is toxic to fish. Excessive algal growth results from the increased concentrations of all nitrogen forms. Ammonia-nitrogen may reduce the potential for water reuse because it adversely affects chlorine disinfection, thereby creating a possible public health hazard. It is important, therefore, to study and control the biological and chemical processes that regulate the concentration of ammonia-nitrogen in treated wastewater effluents. Discharge limitations for ammonia-nitrogen have been placed in the National Pollutant Discharge Elimination System within Public Law 92-500 (currently the Clean Water Act of 1977, Public Law 95-217). Presently existing NPDES permits impose ammonia-nitrogen limitations on Army-produced wastewaters, and it is anticipated that future permits will contain comparable, if not more stringent, discharge limitations.

This report describes phosphorus removal by low-level lime (pH 9.5) precipitation in the primary clarifier, followed by biological recarbonation using the rotating biological contactor (RBC). Of equal importance in this research effort was showing the enhancement of nitrification by

the chemically induced increase in pH. The significance of combining physical and biological treatment of wastewaters was stressed. Goals were set to provide criteria for upgrading existing Army wastewater treatment facilities to meet NPDES permit limitations, as opposed to research directed toward completely replacing such facilities. Considerations in research for design upgrade included maximum use of existing equipment and facilities, simplicity of operation and maintenance, and minimal laboratory support.

LITERATURE REVIEW

Phosphorus

Carbon, as carbon dioxide, is readily available through atmospheric cycles and from natural carbonate alkalinity for assimilation by organisms present in receiving waters. Nitrogen can be drawn from the atmosphere by nitrogen-fixing bacteria, or is available in various forms from surface runoff. However, phosphorus is not available through atmospheric cycles, and it is further limited by its sedimentation cycle. For this reason, Ockershausen,[1] Dogmel and Brooks,[2] and others[3-6] have indicated that phosphorus most frequently limits excessive eutrophication, yet is the most controllable nutrient found in man's wastewaters. The Federal Water Pollution Control Act and Amendments of 1972 (PL 92-500) set a goal of zero discharge for all contaminants.[7] Guidelines from the U.S. Environmental Protection Agency (EPA) and state standards provide additional impetus to remove nutrients from wastewater.[8,9]

Phosphorus removal encompasses several technologies. Biological, chemical-physical, chemical-biological, and physical techniques have successfully removed phosphorus from wastewaters. Biological techniques employ microorganisms to remove phosphorus through synthesis, metabolic processes, and adsorption incorporating the phosphorus into biological solids. Chemical-physical techniques utilize precipitation, coagulation, flocculation, adsorption, sedimentation, and filtration to incorporate the phosphorus in a chemical sludge. Common chemicals used include lime, iron salts, alum, sodium aluminate, and polyelectrolytes. Rare earth elements have also successfully precipitated phosphorus. The technology of phosphorus removal has been reviewed by Ryczak and Miller.[10]

Nitrogen

The biological productivity of surface waters is greatly affected by uncontrolled discharges of soluble forms of nitrogen. Although soluble nitrogen is often considered a fertilizing agent, its immediate effect upon receiving streams is dependent upon its oxidation state. Nitrogen exists at an oxidation state of plus 5 in the form of nitrate or at minus 3 as ammonia. In its most reduced form, ammonia decreases the dissolved oxygen level downstream from its point of discharge. The lowered dissolved oxygen concentrations may be detrimental to aquatic

life. Another problem associated with ammonia is its acute toxicity to fish.[11] Ammonia causes fin and tail decay as well as pathological changes in the gill structures of rainbow trout. Reportedly, ammonia-nitrogen at concentrations of 0.25 to 0.30 mg/l are lethal to fish within 14 to 21 days.[11]

Nitrification

Nitrification is the oxidation of ammonia to nitrate, and denitrification is the reduction of nitrate to nitrogen gas. Different types of microorganisms are required for each action, and the extent of their use in wastewater treatment plants depends upon the end objective. Nitrification is used to control wastewater effluent levels of ammonia, but both nitrification and denitrification are used to control total nitrogen levels in wastewater effluents.

The two microbial genera usually associated with nitrification are *Nitrosomonas* and *Nitrobacter*. Both genera of organisms are autotrophic nitrifying bacteria, indicating that energy for growth is derived from the oxidation of inorganic nitrogen. The oxidation of ammonia to nitrate is a two-step process requiring both organisms for the conversion. *Nitrosomonas* transforms ammonia to nitrite, and *Nitrobacter* further oxidizes nitrite to nitrate.

The overall stoichiometric reactions for ammonia oxidation are listed below.

$$NH_4^+ + 1.5\ O_2 + 2\ HCO_3^- \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2\ H_2CO_3 + H_2O \qquad (1)$$

$$NO_2^- + 0.5\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad (2)$$

$$NH_4^+ + 2\ O_2 + 2\ HCO_3^- \xrightarrow[\text{Nitrobacter}]{\text{Nitrosomonas}} NO_3^- + 2\ H_2CO_3 + H_2O \qquad (3)$$

It can be seen from Equation (1) that carbonate is consumed when ammonia is oxidized by *Nitrosomonas*. As nitrite formation occurs, carbonic acid is produced. This microbiologically induced change in the carbonate buffering system results in the destruction of alkalinity at a rate of 7.1 mg (as $CaCO_3$) per mg of ammonia oxidized.[12-14] As the nitrification process reduces the alkalinity and increases the carbonic acid concentration, the pH of the wastewater may drop as low as 6.0, and adversely impact the rate of nitrification. This decrease in pH can be minimized by aeration to strip CO_2 from the wastewater or by insuring the presence of excess alkalinity.[12]

In addition to nitrification/denitrification, microorganisms require nitrogen for growth. The amount of nitrogen assimilated during oxidation of carbonaceous material has been generally placed at 5 percent of the

oxygen demand (i.e., BOD to N = 20 to 1).[15] The consequence is twofold: (1) nitrogen must be present for biological oxidation of carbonaceous material and (2) removal of ammonia-nitrogen during biological treatment of wastewaters may be due to assimilation, not nitrification.

Rotating Biological Contactor Technology

During the past decade the rotating biological contactor (RBC) process has been studied as a feasible wastewater treatment alternative to activated sludge and trickling filter processes.[16,25] This interest is generated by the ability of the RBC process to provide nitrification as well as oxidation of carbonaceous materials. The RBC consists of a series of vertically mounted, rotating plastic disks of which 40 percent of the surface area is submerged in the wastewater. As the disks rotate, the surface develops a culture of microbiological organisms. The organisms adhere and multiply to form a uniform growth referred to as a fixed film. The biomass, supported by the plastic medium, picks up a thin layer of nutrient-laden water as it rotates through the wastewater. The film of water trickles over the microorganisms which remove dissolved solids and oxygen. The rotation of the disks not only allows for aeration and mixing of the wastewater, but also provides shear forces that cause sloughing of excess growth. RBC units are usually operated in series to remove organic matter with the latter stages providing nitrification.[26,27]

Traditionally, banks of RBC units are operated in series with the number of units depending upon the hydraulic load to be treated. The function of the first stages is to remove organic material, with subsequent stages removing ammonia (when nitrification is necessary to meet effluent standards). Nutrient removal is a function, in part of the hydraulic loading of the system, usually expressed as the volume of wastewater applied to a square measure of surface area per day. A hydraulic loading of 1 to 4 gpd/sq ft is commonly used at standard loading rates for pilot plants and full-scale waste treatment facilities.[19,22,23,25,28]

The change in hydraulic load also changes the organic load as more food is introduced to the active component of the waste treatment system. It has recently been suggested that shortcomings observed in the quality of treatment by RBC units were due to excessive organic loading while operating at less than hydraulic design capacity.[29]

Steiner has reported the necessity for using organic loading as the appropriate parameter for determining the required surface area of an RBC treatment facility.[29] Likewise, Weng and Molof have indicated that BOD removal and nitrification are functions of organic loading and flow rate.[30] Poon _et al_. found 18.4 to 28.6 g BOD/m^2/day to be the optimum organic loading rate for an RBC process.[31]

RESEARCH OBJECTIVES AND APPROACH

The primary objective of this study was to evaluate the performance of the RBC for recarbonation of high pH wastewaters (pH 9.5) following low-level lime addition for phosphorus removal. Secondary treatment and nitrification were monitored as changes in the hydraulic and organic loading rates of the RBC were initiated. The effect of step feed upon nutrient removal and recarbonation were also studied.

From combined reviews of the literature, Army NPDES permits, and existing Army wastewater treatment facilities, it was concluded that phosphorus removal in Army wastewater treatment plants should be limited to chemical precipitation techniques using lime, iron salts, or aluminum salts plus adjunct materials for effective solid-liquid separation. Further, it was concluded that lime addition to pH levels below 10.0 (i.e., low-level lime addition) should be a prime candidate for phosphorus removal due to the simplicity of process control, reliability, economic desirability and potential effectiveness.

The RBC process was selected for evaluation for recarbonation of high pH wastewaters (pH 9.5) by secondary treatment and its ability to nitrify these same wastewaters, depending on the loading rate. The choice of this treatment scheme considered the relatively low energy and operating costs of the RBC process, simplicity of operation, and flexibility with respect to the up-grading of existing treatment plants.

MATERIALS AND METHODS

Pilot studies used domestic wastewater from the Fort Detrick housing area. The wastewater was shredded by a grinder pump and pumped at 7 gpm into a 250-gallon tank that acted as an equalization chamber. The raw, degritted wastewater was pumped to the rapid mix tank where lime was added. The wastewater (with elevated pH) then flowed by gravity to the flocculation basin, through the primary settling basin, to the RBC, and a secondary settling basin. A schematic of the wastewater flow route is shown in Figure 1.

The lime feed system consisted of a lime slurry tank, a rapid mix tank, and an automatic pH control system. The lime slurry tank contained a 2 percent slurry of $Ca(OH)_2$ and was continuously mixed. The rapid mix tank had a detention time of about 5 minutes, depending upon flow rate. The pH measurement for automatic control was taken in the flocculation basin. The off-on time of the lime slurry feed pump was controlled by feedback from the pH unit. Ferric chloride feed for effective solid-liquid separation was used as an integral part of the lime feed system. The ferric chloride was fed into the wastewater at the rapid mix tank, prior to flocculation at 5 mg/L (as Fe).

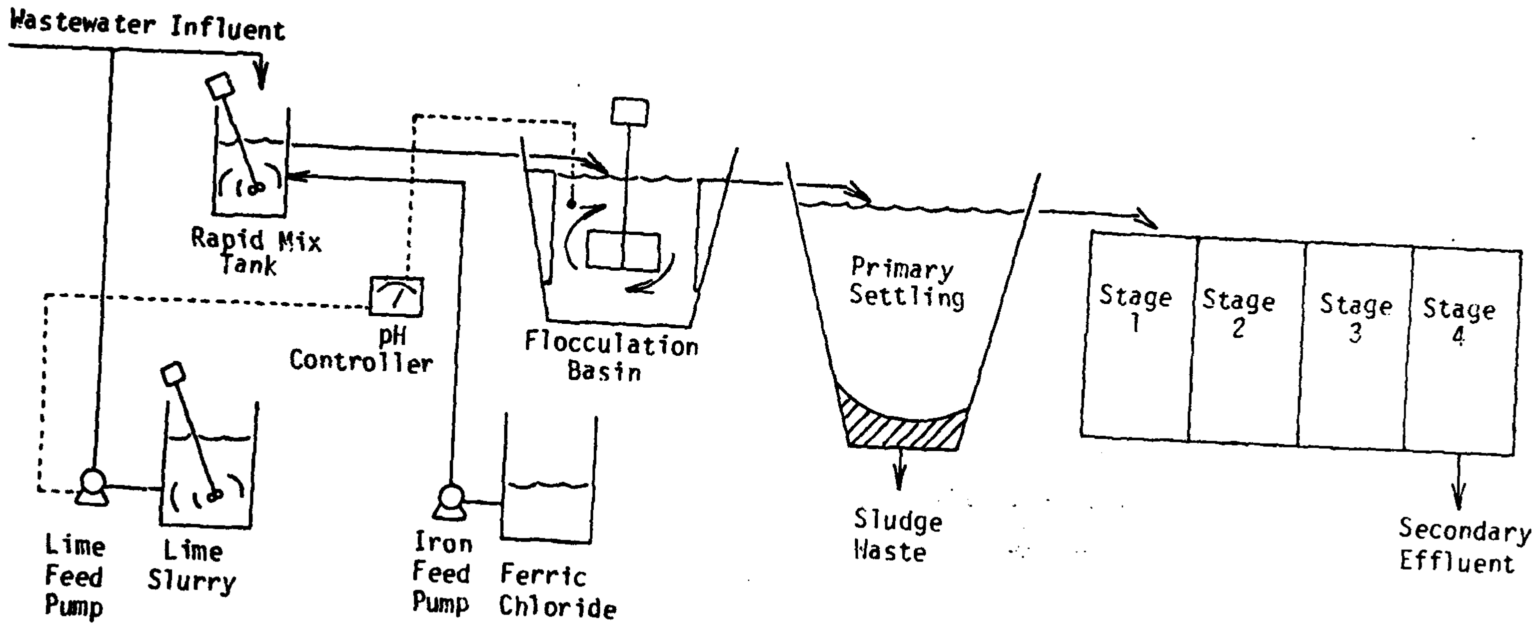

Figure 1. Schematic of the Pilot-Scale Lime Addition and Secondary Treatment Processes.

The flocculation basin has a detention time of about 30 minutes. Mixing was provided by a double paddle rotating at 15 rpm. Baffles were used as part of the flocculation basin to obtain effective floc formation. The primary settling basin had a detention time of 2 to 3 hours depending on flow rate.

The rotating biological contactor consisted of four compartments in series. The 0.5-meter plastic media disks provided 250 sq ft of surface area for microbial attachment. The disk was rotated through the liquor at 13 rpm with 40 percent of the fixed film submerged at any point.

Total organic carbon (TOC) measurements were made on a Beckman Model 915 total organic carbon analyzer. Ammonia-nitrogen concentrations were measured with Orion specific ion electrode. Dissolved oxygen and BOD determinations were made using a Delta Scientific Model 2110 dissolved oxygen meter and probe. Chemical oxygen demand (COD), total Kjehdahl nitrogen, and phosphorus analyses were made using a Technicon AutoAnalyzer II system according to U.S. EPA-approved Technicon methods. Samples were filtered through fiberglass filters, except for phosphorus samples, which were filtered through 0.45-μm membrane filters. All other analyses were performed according to Standard Methods.[32]

The rotating biological contactor was evaluated for secondary treatment and recarbonation in conjunction with the low-level lime addition method for phosphorus removal. The RBC was evaluated at pH 9.5 at flow rates of 2.0, 3.0, and 4.0 gpd/sq ft and pH 7.0 at 3.0 gpd/sq ft. The RBC was evaluated at pH 9.5 and 2.5 gpd/sq ft with 30 and 50 percent of the flow feed into Cell 3. All evaluations were accomplished at a wastewater temperature of 15° to 25°C.

RESULTS AND DISCUSSION

The rotating biological contactor was initially evaluated for secondary treatment and recarbonation of high pH wastewaters (pH 9.5) derived from low-level lime addition before primary settling for the purpose of phosphorus removal. The hydraulic loading rates tested were 2.0, 3.0, and 4.0 gpd/sq ft. Secondary treatment efficiency was evaluated using filtered and unfiltered BOD_5 and filtered TOC. The degree of treatment received was also determined by monitoring the extent of nitrification at various loading rates. Suspended solids, pH, temperature, and dissolved oxygen levels within the RBC stages were monitored. Sample points included raw wastewater, lime-treated primary-clarified effluent, and RBC effluent. Limited sampling was conducted within the stages of the RBC to evaluate the progression of treatment.

Characteristics of the raw, degritted wastewater are shown in Table 1. Wastewater parameters were found to remain relatively constant on a daily basis, but fluctuations did exist on a seasonal basis.

TABLE 1. CHARACTERIZATION OF RAW, DEGRITTED WASTEWATER

Parameter	Mean Concentration (Annual Average)
BOD_5, Filtered (mg/L)	113
TOC, Filtered (mg/L)	73
COD, Filtered (mg/L)	163
Suspended Solids (mg/L)	107
NH_3-N (mg/L)	17.0
Alkalinity (mg/L)	148
pH[a]	7.1
Phosphorus, Soluble (as P) (mg/L)	8.6
Total Phosphorus (as P) (mg/L)	10.8

a. Median value.

Chemical Addition

Lime was added to the wastewater influent to elevate the pH to 9.5. Ferric chloride (5 mg/L as Fe) was also added to the influent during the rapid mix as a flocculant aid. Approximately 3.0 mg/L of soluble phosphorus (as P) remained before secondary treatment. Figure 2 depicts the removal of phosphorus by both chemical-physical and biological means. About 75 percent of the soluble phosphorus was removed by the low-level lime addition technique. Additional phosphorus removal was achieved through biological assimilation. The secondary effluent phosphorus concentrations were usually 2.0 mg/L (as P).

Table 2 shows the beneficial effect of low-level lime addition on nutrient removed during secondary treatment. The RBC received primary-clarified wastewater at a hydraulic loading rate of 3.0 gpd/sq ft and pH 9.5. No differences in BOD_5 or COD removals were observed. Percent removal of TOC and phosphorus was greater when the low-level lime addition process was employed. The most notable difference was observed in ammonia-nitrogen removal. The percent removal of ammonia-nitrogen (at high pH) was more than twice the observed removal rate when no pH adjustment was used. Figures 3 and 4 further depict the efficacy of the lime addition process for enhancement of secondary treatment. Figure 3 shows the soluble

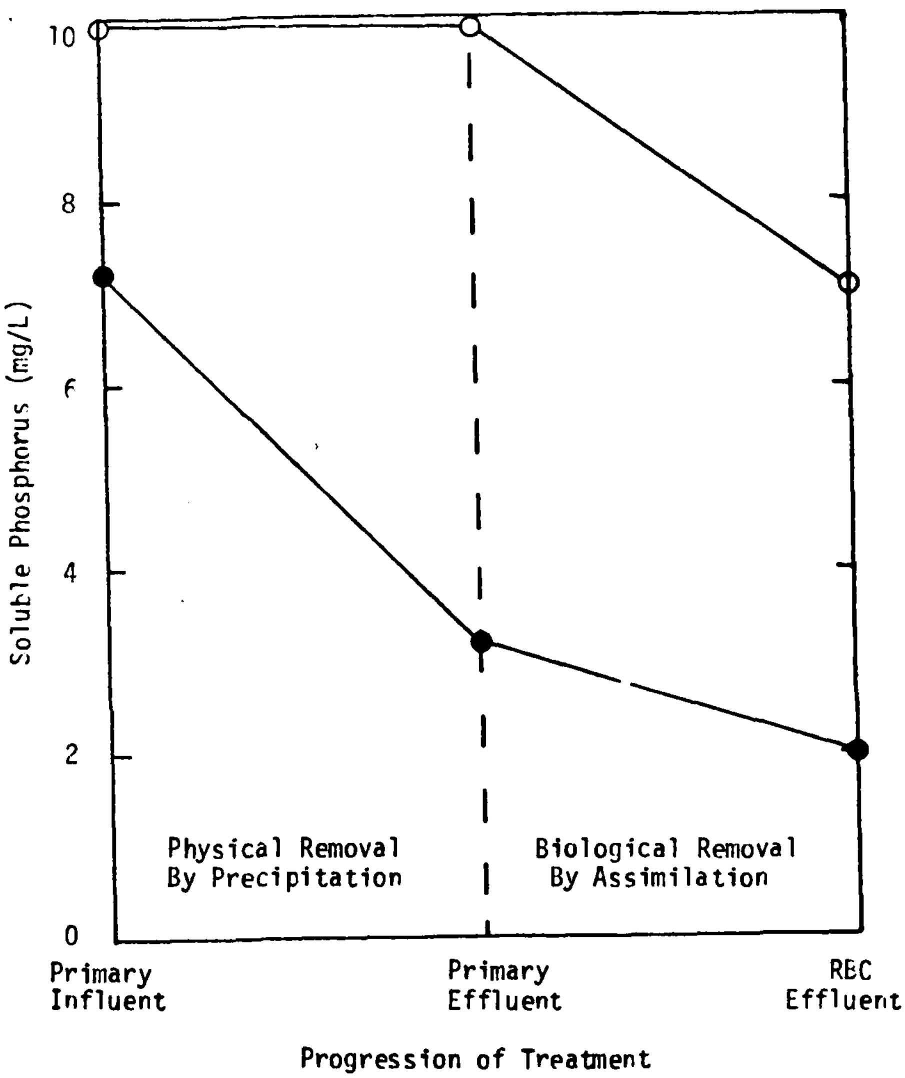

Figure 2. Physical and Biological Aspects of Phosphorus Removal. Solid circles represent wastewater treated with lime to achieve a pH value of 9.5, followed by primary settling for removal of phosphorus precipitate. Open circles are results from control experiments where no chemical was added to the wastewater. The hydraulic loading rate was 3.0 gpd/sq ft.

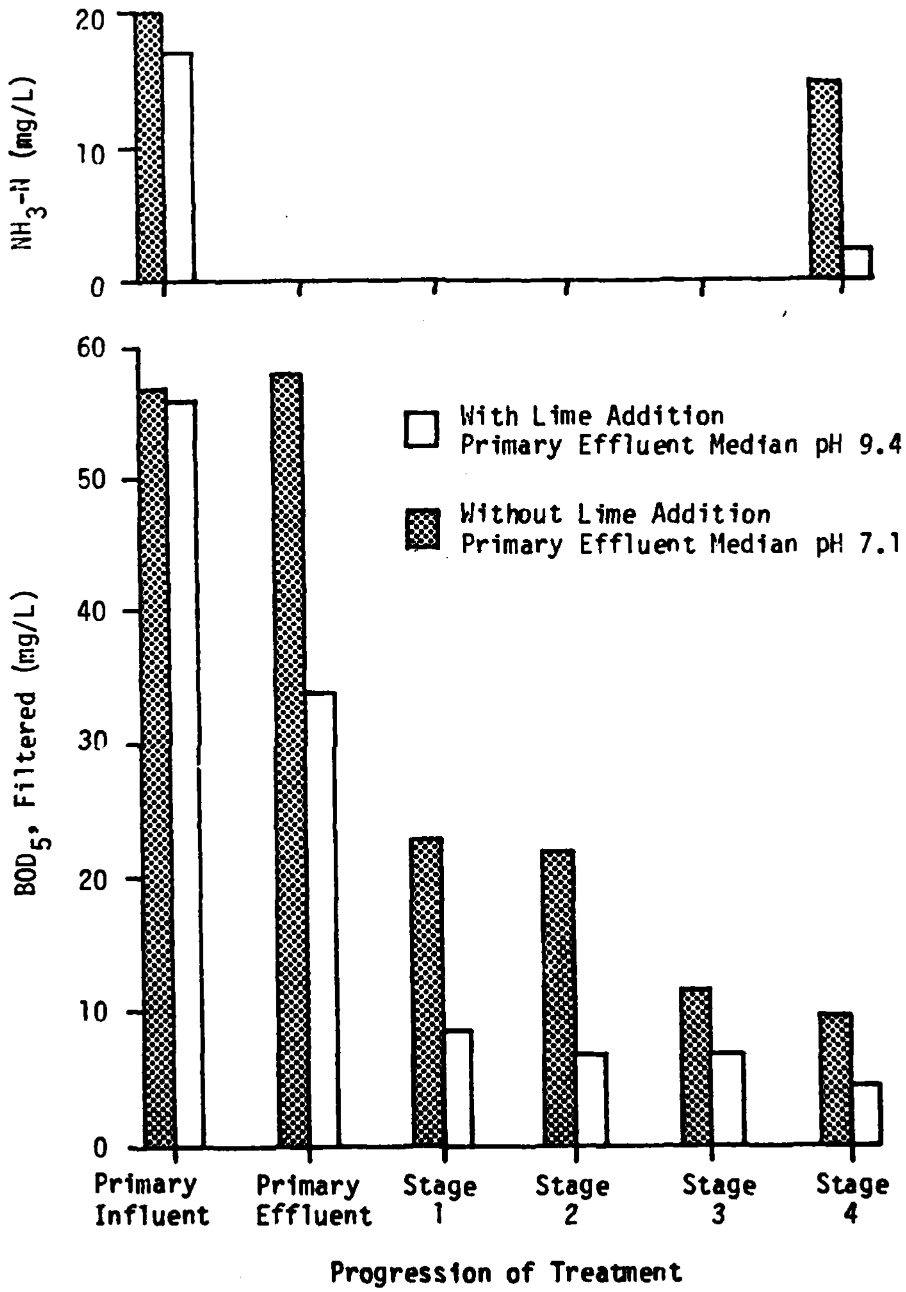

Figure 3. Soluble BOD_5 Concentrations and Influent and Effluent Ammonia Concentrations with Respect to the Progression of Treatment. The hydraulic loading rate was 3.0 gpd/sq ft for both conditions.

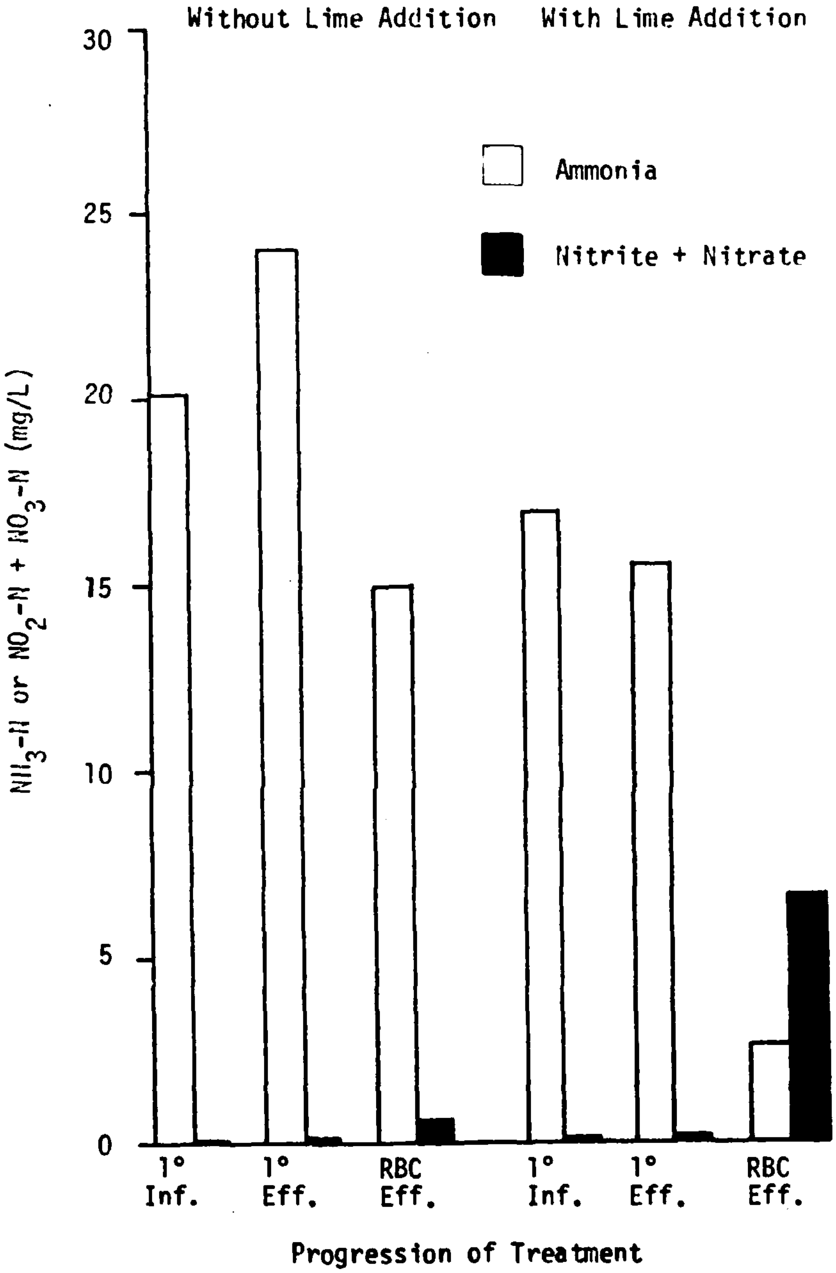

Figure 4. Nitrification by NH_3-N Conversion to NO_2-N + NO_3-N With Respect to the Amount of Treatment Received. Ammonia and nitrite plus nitrate levels are shown with and without lime addition at 3.0 gpd/sq ft.

TABLE 2. EFFECT OF LOW-LEVEL LIME ADDITION ON NUTRIENT REMOVAL RATES EXPRESSED AS PERCENTAGES[a]

Parameter	Percent Removed	
	With Lime Pretreatment	Without Lime Pretreatment
BOD, Unfiltered	88	87
BOD_5, Filtered	92	92
TOC, Filtered	64	45
COD, Filtered	70	71
Phosphorus, Soluble (as P)[b]	37	24
NH_3-N	83	40

a. RBC influent pH values were 9.3 and 7.1 for wastewaters with and without lime addition, respectively. The hydraulic loading rate was 3.0 gpd/sq ft.

b. Due to assimilation only, does not include chemical precipitation.

BOD_5 concentrations with respect to the progression of treatment with and without low-level lime addition at a hydraulic loading rate of 3.0 gpd/sq ft. In each case, the primary influent soluble BOD_5 was essentially the same. However, a small portion of the soluble BOD_5 was removed by the low-level lime addition technique for phosphorus removal.

The difference in BOD_5 reduction by the first stage of the RBC was quite apparent when comparing removal rates with and without low-level lime addition. Eighty percent of the BOD_5 was removed from the high pH wastewater effluent, whereas only 58 percent was removed without an initial pH adjustment. This difference indicates that more RBC surface area is available for autotrophic nitrifiers, thereby allowing for the increased nitrification shown in the top panel of Figure 3.

Nitrification was achieved when the lime addition process for phosphorus removal was incorporated into the wastewater treatment train. Figure 4 illustrates the conversion of ammonia to nitrite plus nitrate. Nitrification is shown relative to the treatment processes with and without the addition of lime. When no lime was added for phosphorus removal and consequent elevation of influent pH, little ammonia was converted to

nitrite and nitrate. However, the addition of lime to the influent wastewater allowed for a substantial conversion of ammonia to nitrite and nitrate. The low-level lime addition technique for phosphorus removal not only achieves its primary function, phosphorus removal as shown in Figure 2, but also allows for nitrification without increased surface area.

Hydraulic Loading

Table 3 compares nutrient removal at hydraulic loading rates of 2.0, 3.0, and 4.0 gpd/sq ft. At the higher flow rates (3.0 and 4.0 gpd/sq ft), the wastewater pH was lowered more slowly by the biological degradation of carbonaceous materials. Little variation in phosphorus removal was observed, but ammonia-nitrogen removal decreased dramatically. RBC effluent ammonia-nitrogen levels increased from 2.7 mg/L at 3.0 gpd/sq ft to 18.6 mg/L at a hydraulic loading rate of 4.0 gpd/sq ft. This indicates that nitrification did not occur, most likely as a result of increased RBC surface area requirements for BOD removal.

The percent removal of BOD remained constant as the loading rate was increased to 4.0 gpd/sq ft (Table 4). However, the percent removal of COD, TOC, and NH_3-N declined sharply at the elevated hydraulic loading rate. Figure 5 further illustrates the negative effect of increased hydraulic and organic loading rates on nutrient removal. As a reference, nutrient removal efficiencies are also shown when no lime was added for phosphorus removal at a hydraulic loading rate of 3.0 gpd/sq ft.

Table 5 shows the mean concentrations of test parameters prior to and after secondary treatment at a hydraulic loading rate of 4.0 gpd/sq ft following low-level lime addition for phosphorus removal. On the average, 58 mg/L of soluble BOD were utilized by organisms in the RBC. Twice as much BOD was degraded by these organisms as TOC (27 mg/L). According to Clark and Viessman,[15] under these conditions, ammonia-nitrogen would be assimilated by heterotrophic organisms at 5 percent of the BOD utilization. Therefore, 2.9 mg/L ammonia-nitrogen should have been assimilated by the fixed film (0.05 x 58 mg/L BOD utilized = 2.9). This compares favorably to the observed drop in ammonia-nitrogen of 2.3 mg/L. Also confirming these calculations is the fact that no alkalinity was destroyed, thereby indicating the lack of nitrification.

Figure 6 illustrates pH values expressed as a function of the biological treatment received. At 3.0 gpd/sq ft, little difference in pH was observed without chemical addition for phosphorus removal. During the period when lime was added to elevate the pH to 9.5 for phosphorus removal, the degree of recarbonation decreased with increasing flow rate. Adequate recarbonation and secondary treatment were achieved at all hydraulic loadings tested; however, the degree of nitrification varied.

TABLE 3. COMPARISON OF NUTRIENT REMOVAL AT THREE HYDRAULIC LOADING RATES

Parameter	Mean Concentrations, Hydraulic Loading (gpd/sq ft) 2.0	3.0	4.0
pH[a]			
Primary Effluent	9.5	9.3	9.4
RBC Effluent	7.0	7.2	7.9
Phosphorus (as P) (mg/L)			
Influent Soluble Phosphorus	10.5	7.2	9.7
Primary Effluent Soluble Phosphorus	3.8	3.2	3.3
RBC Effluent Soluble Phosphorus	2.3	2.0	2.0
Ammonia (as N) (mg/L)			
RBC Influent Ammonia	17.0	15.6	20.9
RBC Effluent Ammonia	2.4	2.7	18.6

a. Median value.

TABLE 4. EFFECT OF HYDRAULIC LOADING RATES ON NUTRIENT REMOVAL EXPRESSED AS PERCENTAGES[a]

Parameter	Percent Removed 2.0 gpd/sq ft	3.0 gpd/sq ft	4.0 gpd/sq ft
BOD_5, Filtered	97	92	91
TOC, Filtered	66	64	49
COD, Filtered	81	70	43
NH_3-N	86	83	20

a. The RBC influent pH values were pH 9.5, 9.3, and 9.4 for the loading rates of 2.0, 3.0, and 4.0 gpd sq ft, respectively.

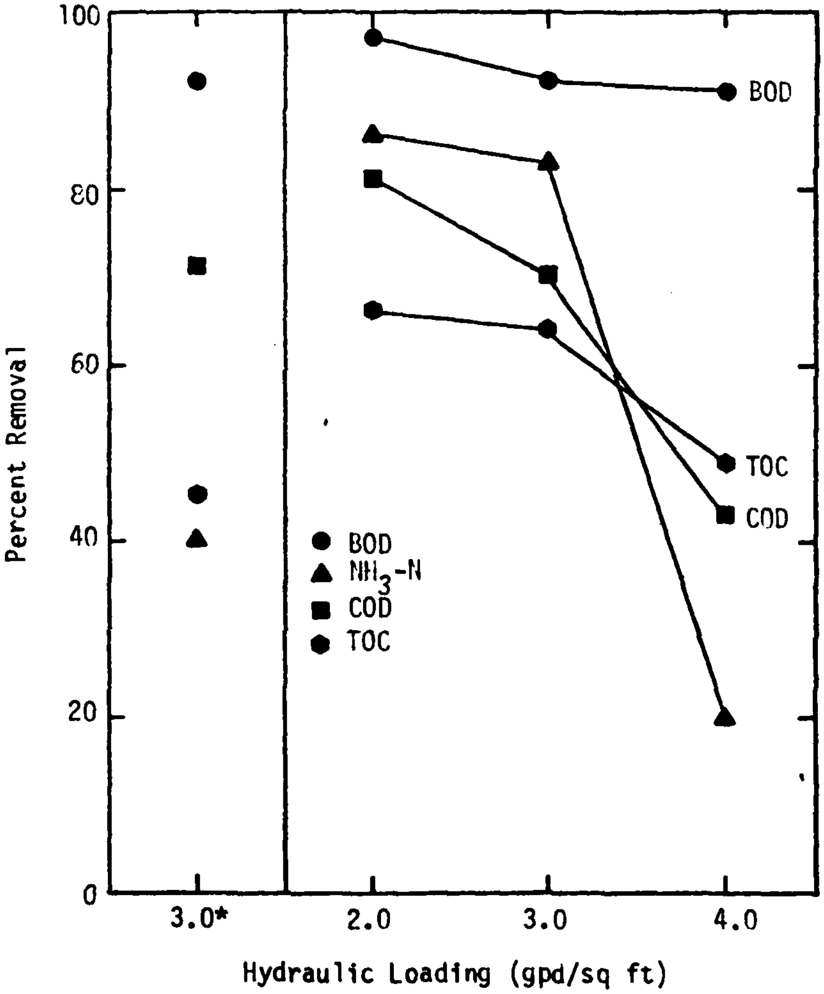

Figure 5. Percent Removal of Nutrients With Respect to Hydraulic Loading Rate. The wastewater was pretreated with lime to pH 9.5 for phosphorus removal.

* The left-hand panel shows the percent removal for each parameter when no lime was added for phosphorus removal.

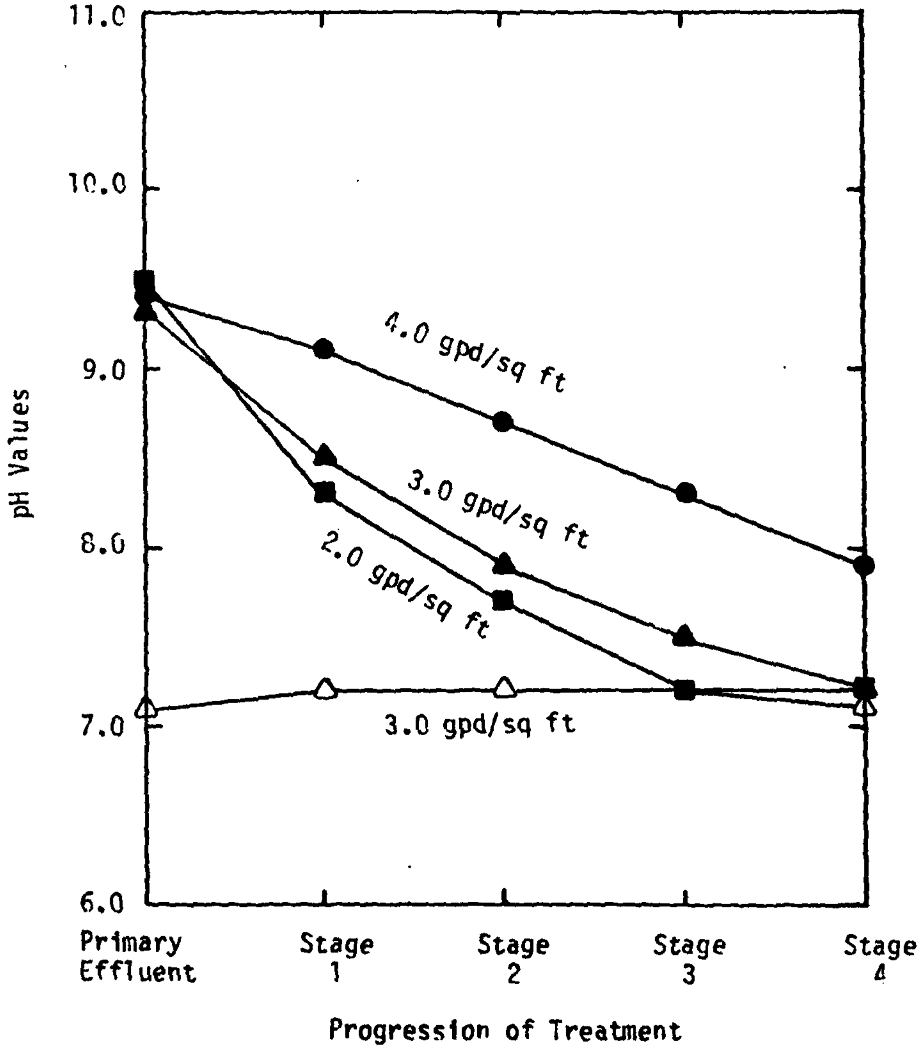

Figure 6. pH Values as a Function of Biological Treatment Received. Circles, triangles, and squares represent the biological recarbonation effect on wastewater at 2.0, 3.0, and 4.0 gpd/sq ft, respectively. The solid symbols represent wastewater that was pretreated with lime for phosphorus removal. The open triangles show the constancy of pH values when no lime was added.

TABLE 5. MEAN CONCENTRATION OF TEST PARAMETERS PRIOR TO AND AFTER SECONDARY TREATMENT[a]

Parameter	Mean Concentrations	
	RBC Influent	RBC Effluent
BOD_5 (mg/L)	100	25
BOD_5, Filtered (mg/L)	62	4
TOC, Filtered (mg/L)	55	28
COD, Filtered (mg/L)	182	104
Alkalinity, Filtered (mg/L)	250	244
Phosphorus, Soluble (as P) (mg/L)	3.3	2.2
Ammonia (as N) (mg/L)	20.9	18.6
Temperature (°C)	20.1	21.0
pH[b]	9.4	7.9

a. Hydraulic loading rate on the RBC was 4.0 gpd/sq ft following low-level lime addition for phosphorus removal.
b. Median value.

Figure 7 shows the recarbonation of high pH wastewater through increases of inorganic carbon levels. Inorganic carbon levels are expressed as a function of the influent concentration, which ranged from 30 to 38 mg/L. The production of CO_2 increased with greater hydraulic loading rates and corresponding increase in organic loading. Even though higher levels of inorganic carbon were found at the greater hydraulic loading rates, pH depression proceeded more slowly.

Figure 8 depicts the ammonia-nitrogen concentrations throughout the wastewater treatment system. The figure shows the ammonia-nitrogen concentrations in the primary effluent, settled primary effluent, and RBC effluent at hydraulic loading rates of 2.0, 3.0, and 4.0 gpd/sq ft. In each case, ammonia-nitrogen levels were unaffected by the lime addition process. However, only when the total RBC surface area was required for BOD removal at 4.0 gpd/sq ft did ammonia-nitrogen appear in significant quantities in the secondary effluent. Figure 7 substantiates the lack of ammonia removal at 4.0 gpd/sq ft as there was no decrease in inorganic carbon, which is indicative of nitrification and concomitant changes in the carbonate buffering system.

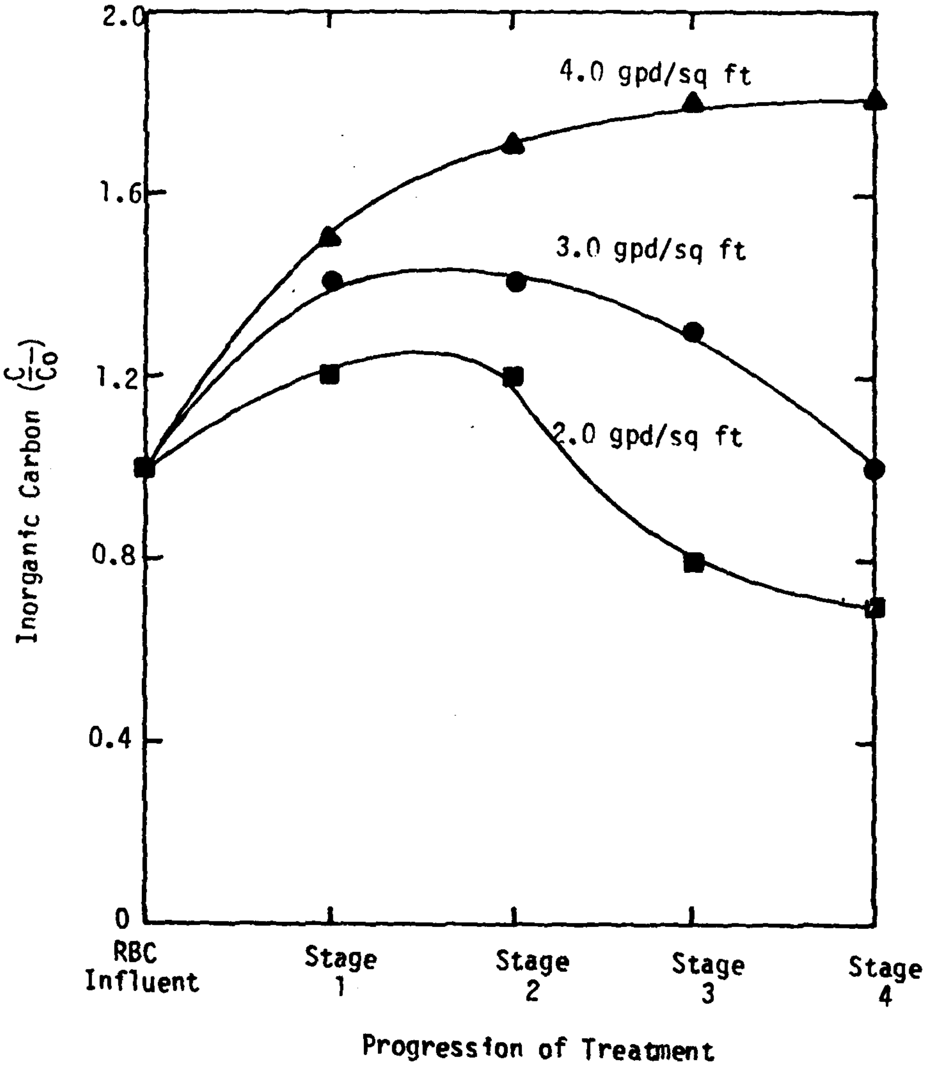

Figure 7. Inorganic Carbon Produced through Biological Oxidation of Organic Substrates at Various Hydraulic Loading Rates. Inorganic carbon levels are expressed as a function of the influent concentration, which ranged from 30 to 38 mg/L.

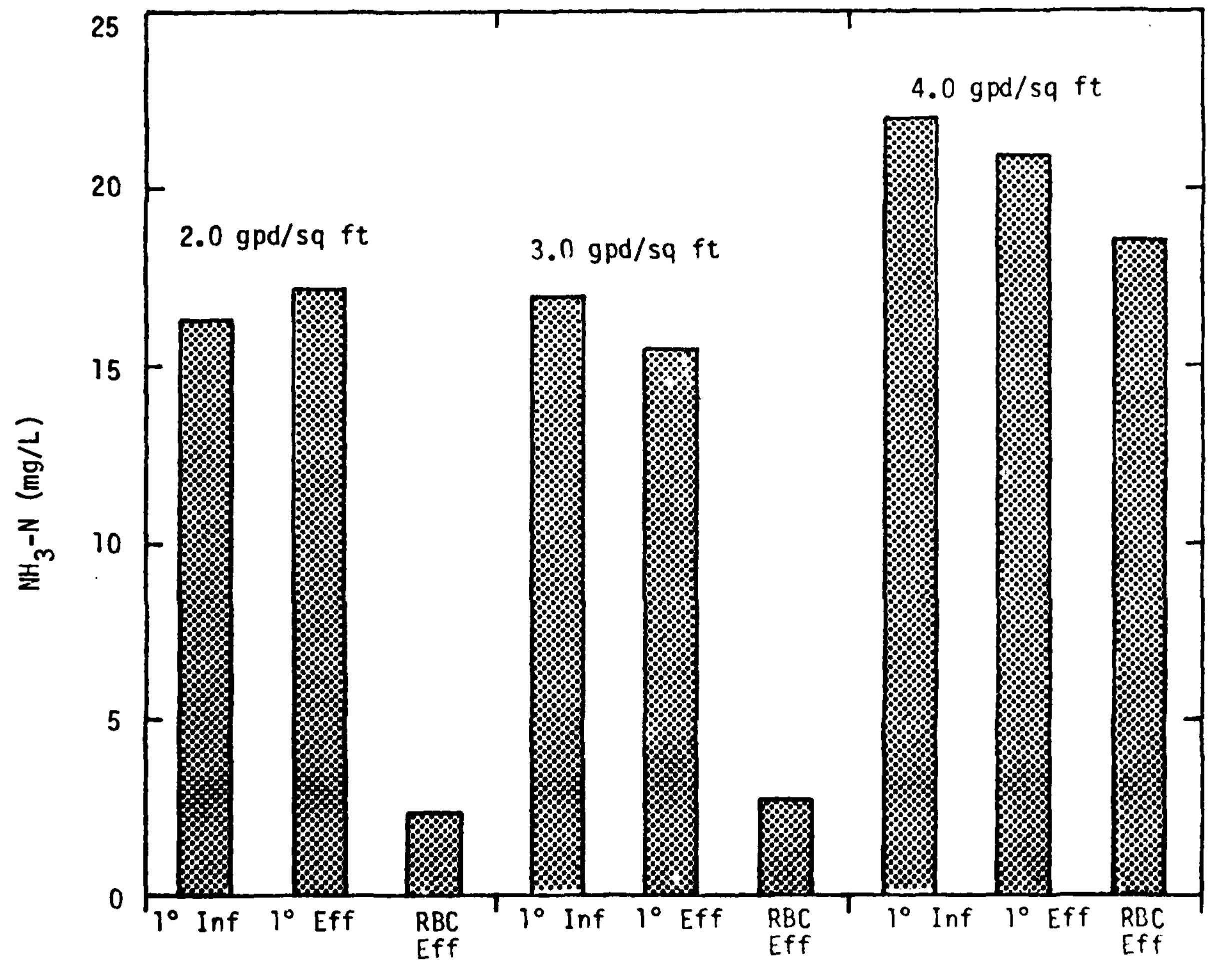

Figure 8. Ammonia-nitrogen Concentrations throughout the Wastewater Treatment System at Varied Hydraulic Loading Rates. (At each loading rate, the RBC received wastewater that was pretreated with lime for phosphorus removal.)

Step-Feed Studies

Primary-clarified wastewater, having a pH of 9 to 9.5, was applied to the RBC at an overall hydraulic loading rate of 2.5 gpd/sq ft. During control studies, 100 percent of the flow was applied to the first RBC stage and then passed through the successive stages. The two experimental trials diverted 30 percent, and later 50 percent, of the RBC influent to the third stage. Nutrients removed during these tests are shown in Table 6. Large differences in the removal of organic constituents were not observed. The 70/30 split of wastewater influent demonstrated the least degree of treatment, but was attributable to inorganic chemicals appearing in the wastewater as indicated by an increase in COD levels. This elevated COD load did exert an effect on nutrient removal, but did not greatly affect wastewater recarbonation. Table 7 shows the pH depression and TOC removal across the RBC stages.

Figure 9 shows the TOC concentrations in the RBC stages at the various wastewater feed conditions. However, the numbers reported as mg/L are not an accurate measure of removal because more wastewater was applied to the latter RBC stages, but they are representative of the expected effluent concentrations. Figure 10 illustrates TOC removal on a mass per unit area per unit time basis. Even though the 100/0 wastewater application scheme had the lowest initial TOC concentration, it had a relatively high loading rate because none of the flow was diverted to stage 3 as in the other studies. The addition of primary-clarified wastewater to the third RBC stage has resulted in increased TOC removal in the latter stages, but not necessarily an increase in overall removal. As seen in Table 7, the highest percent removal of TOC was observed when the flow was split between stages 1 and 3; yet the lowest effluent concentration was achieved without splitting of the flow. Figure 11 demonstrates the cumulative percent removal of TOC by the three flow application schemes. No large differences were observed in the overall removal for each treatment scheme. However, splitting of the wastewater flow appears to better utilize the available RBC media surface area with respect to its ability to recarbonate high pH wastewaters.

Biologically induced pH depression was observed with all three loading schemes. The initial reduction of pH in the first two stages was greater with respect to the longer retention times resultant of flow splitting (Fig. 12). No adverse effects were observed as a result of introducing high pH wastewater into the third RBC stage. Figures 13 and 14 express recarbonation as a function of the amount of inorganic carbon produced. Figure 13 shows the actual concentration of inorganic carbon present in the RBC stages. Inorganic carbon is produced in stage 1 where much of the BOD and TOC was degraded by microorganisms. As the wastewater pH decreases, aeration continues, and nitrification ensues, the inorganic carbon levels decline across the RBC. When wastewater was applied to the third stage, the production of inorganic carbon again exceeded its removal. The open symbols are expected values if additional wastewater had not been applied to the third RBC stage (Figs. 13 and 14). The additional

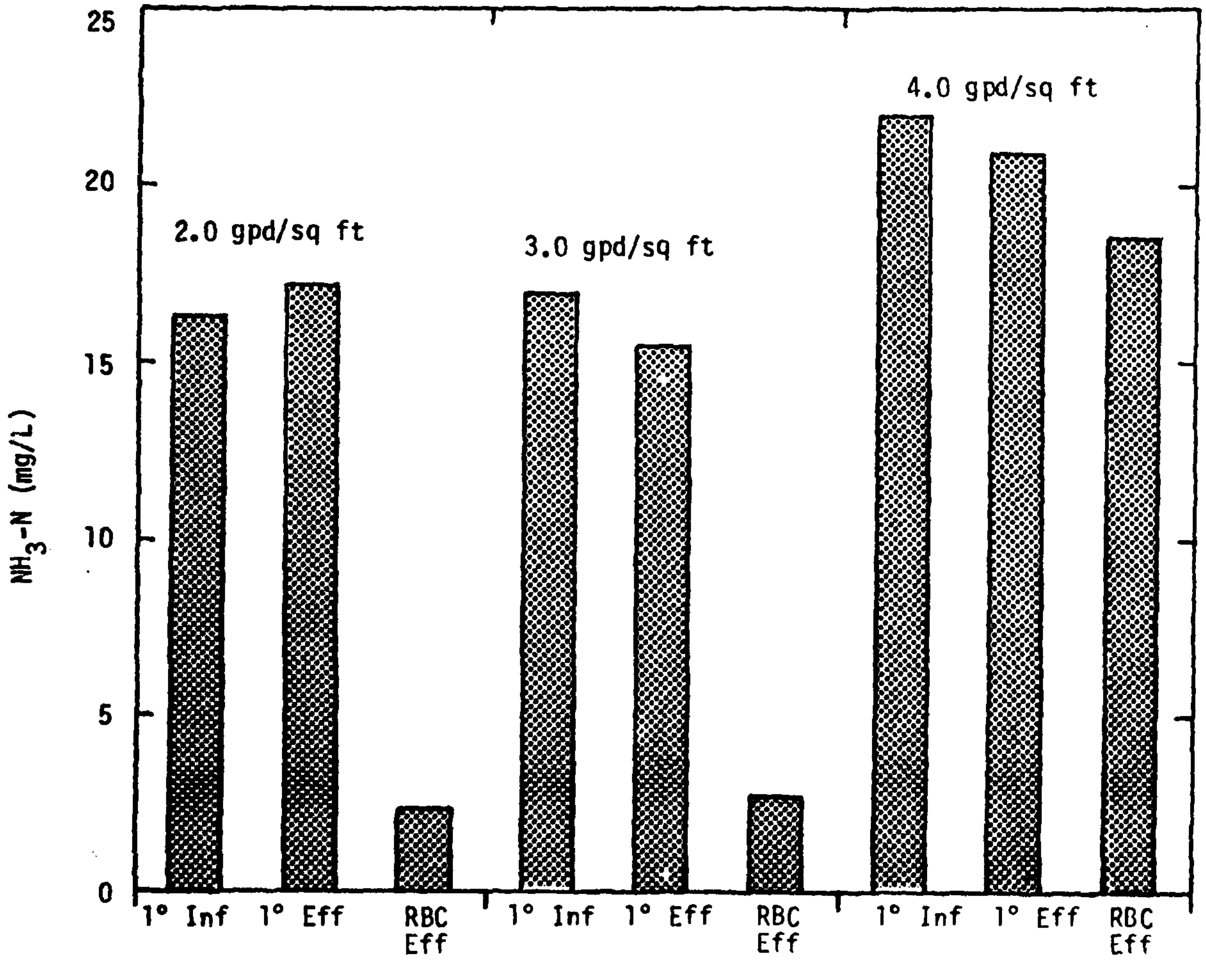

Figure 8. Ammonia-nitrogen Concentrations throughout the Wastewater Treatment System at Varied Hydraulic Loading Rates. (At each loading rate, the RBC received wastewater that was pretreated with lime for phosphorus removal.)

TABLE 6. NUTRIENT REMOVED BY SECONDARY TREATMENT[a]

	100% to Stage 1			70/30 Split to Stages 1 & 3			50/50 Split to Stages 1 & 3		
	RBC Inf	RBE Eff	% Removed	RBC Inf	RBC Eff	% Removed	RBC Inf	RBC Eff	% Removed
BOD, Unfiltered	67	11	84	77	12	84	103	12	88
BOD, Unfiltered	45	3	93	53	7	87	64	4	94
TOC	54	26	48	67	38	57	65	29	55
Alkalinity	234	157	-	230	201	-	255	197	-
COD	118	20	83	277	132	52	157	37	83
NH_3-N	14.2	3.5	75	22.2	12.6	43	19.9	7.2	64
NO_2+NO_2	9.10	7.14	-	0.33	6.32	-	0.11	10.19	-
Suspended Solids	42	11	74	57	37	40	60	13	78
pH[b]	9.2	7.5	-	9.3	7.8	-	9.2	7.6	-

a. The RBC received a hydraulic loading of 2.5 gpd/sq ft.
b. Median value.

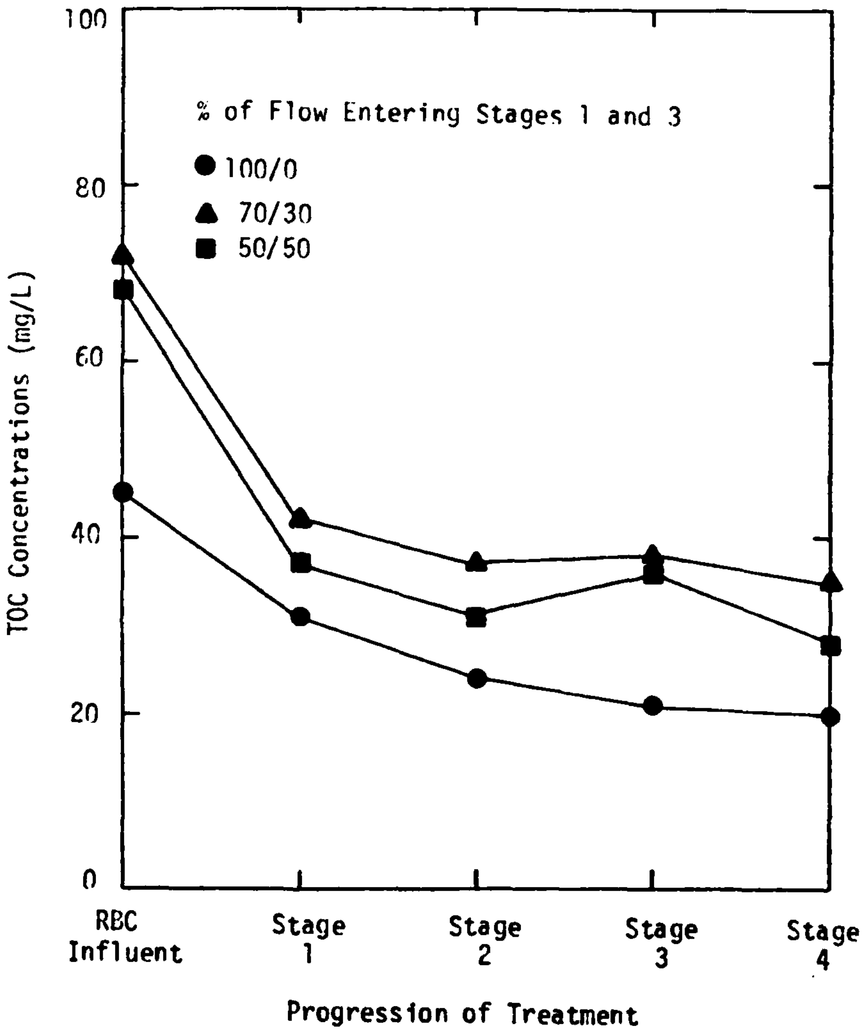

Figure 9. TOC Concentrations in the RBC Influent and within the RBC Stages.

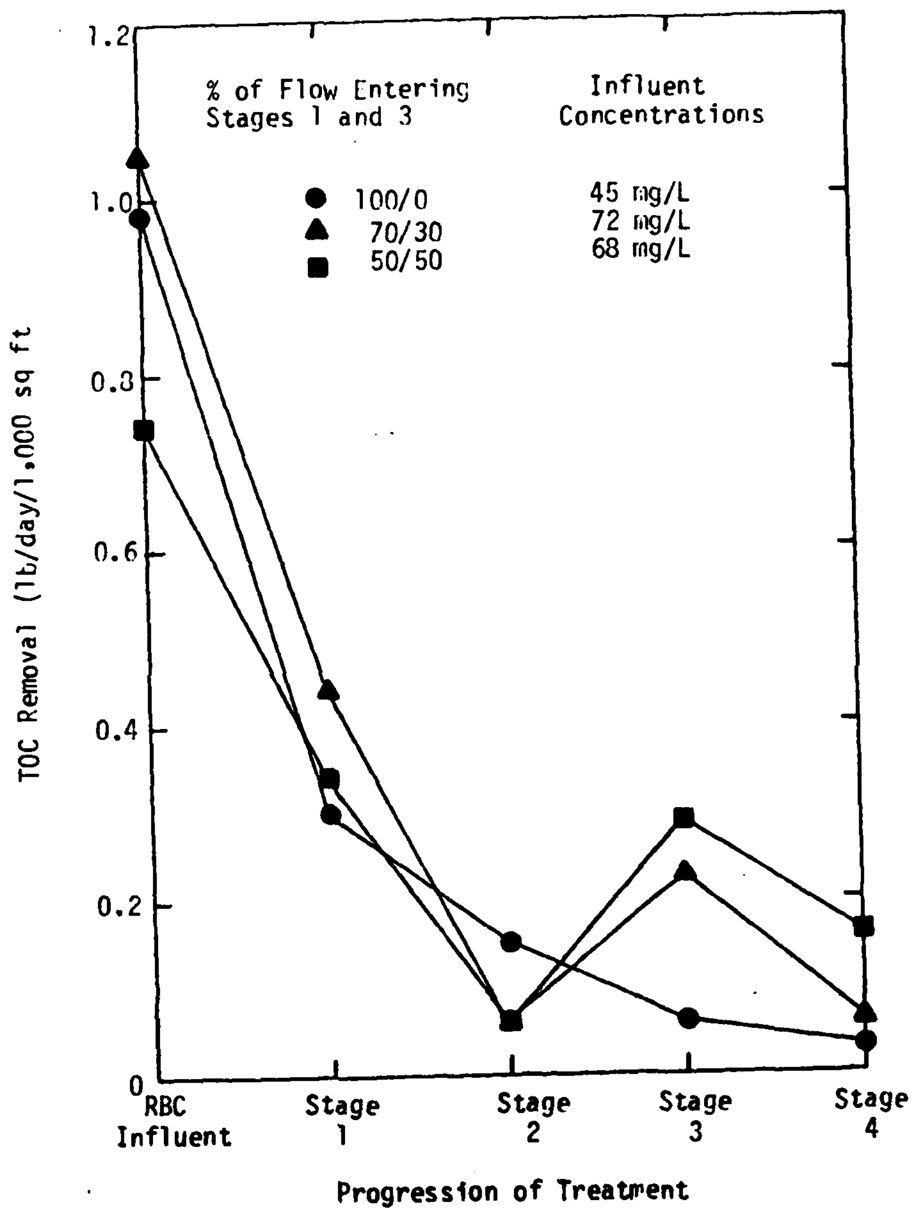

Figure 10. Pounds of TOC Removed/Day/1000 sq ft for Each RBC Stage.

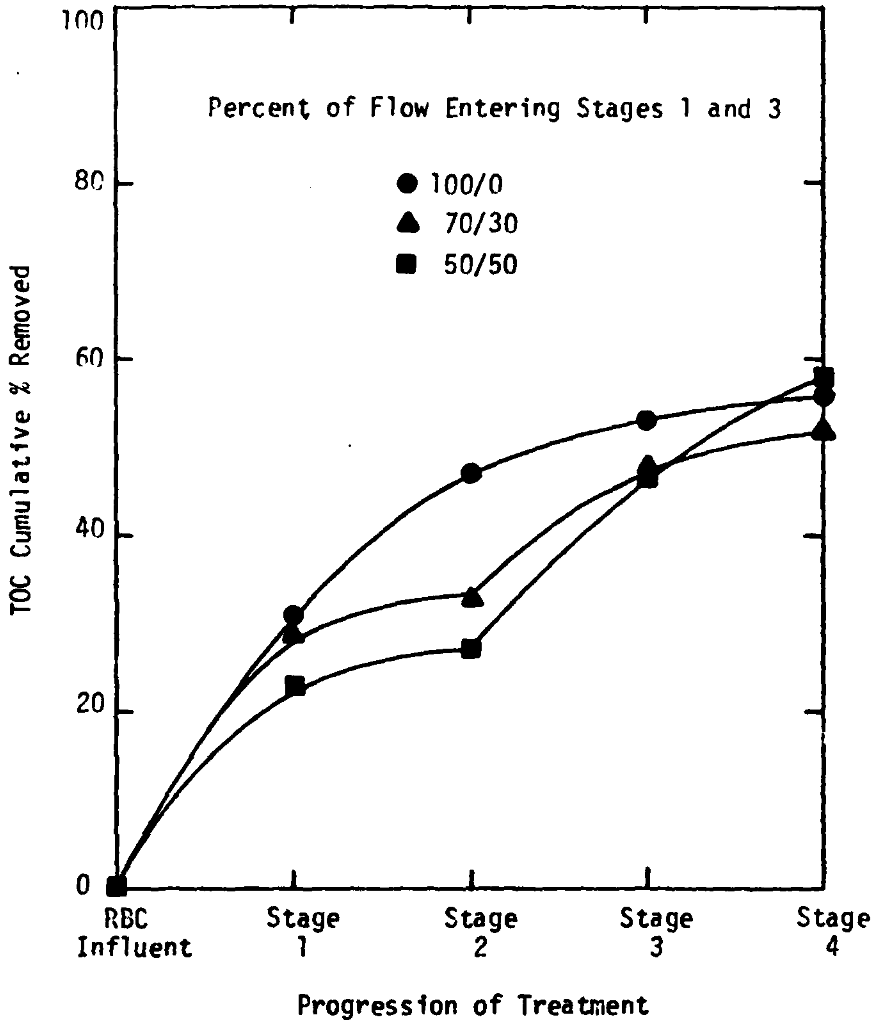

Figure 11. Cumulative Percent Removal of TOC with Respect to the Degree of Biological Treatment Received.

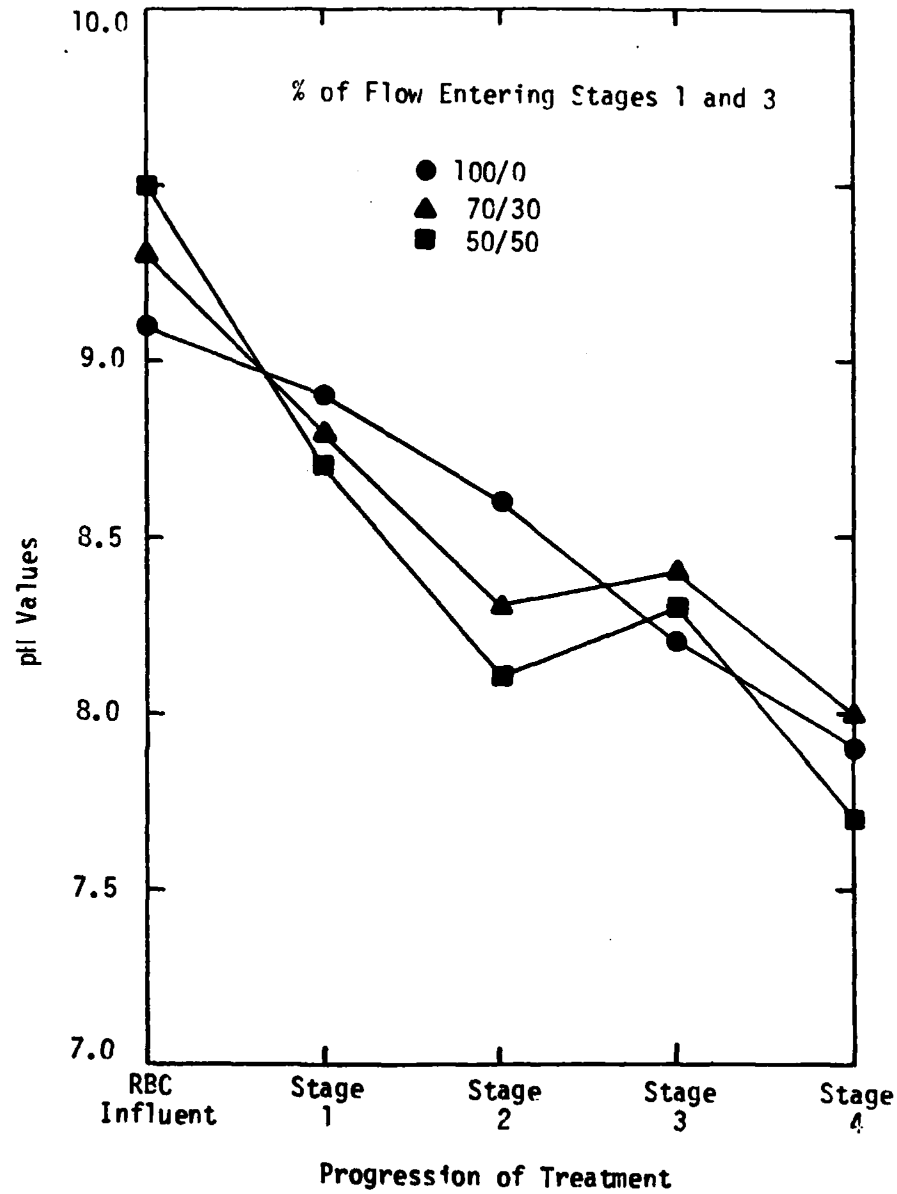

Figure 12. Recarbonation by the Depression of pH within Each RBC Stage.

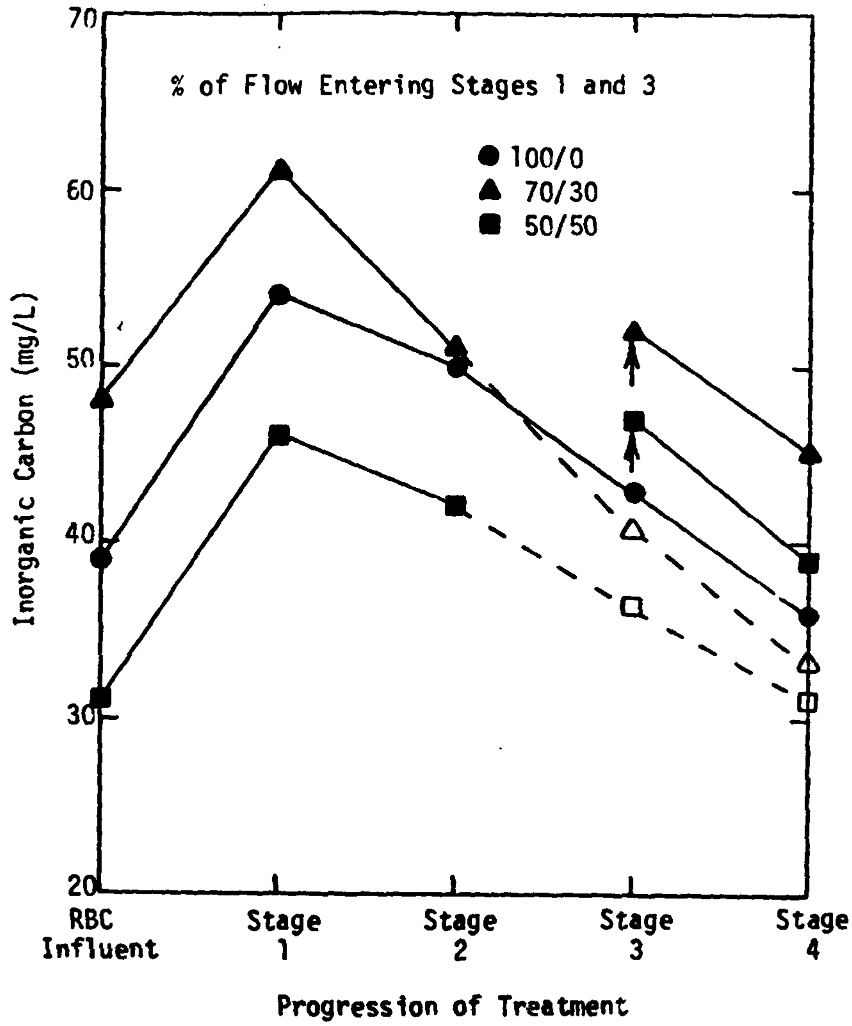

Figure 13. Concentrations of Inorganic Carbon in the RBC Influent and Each Stage. Open symbols are the expected values if additional wastewater had not been applied to stage 3.

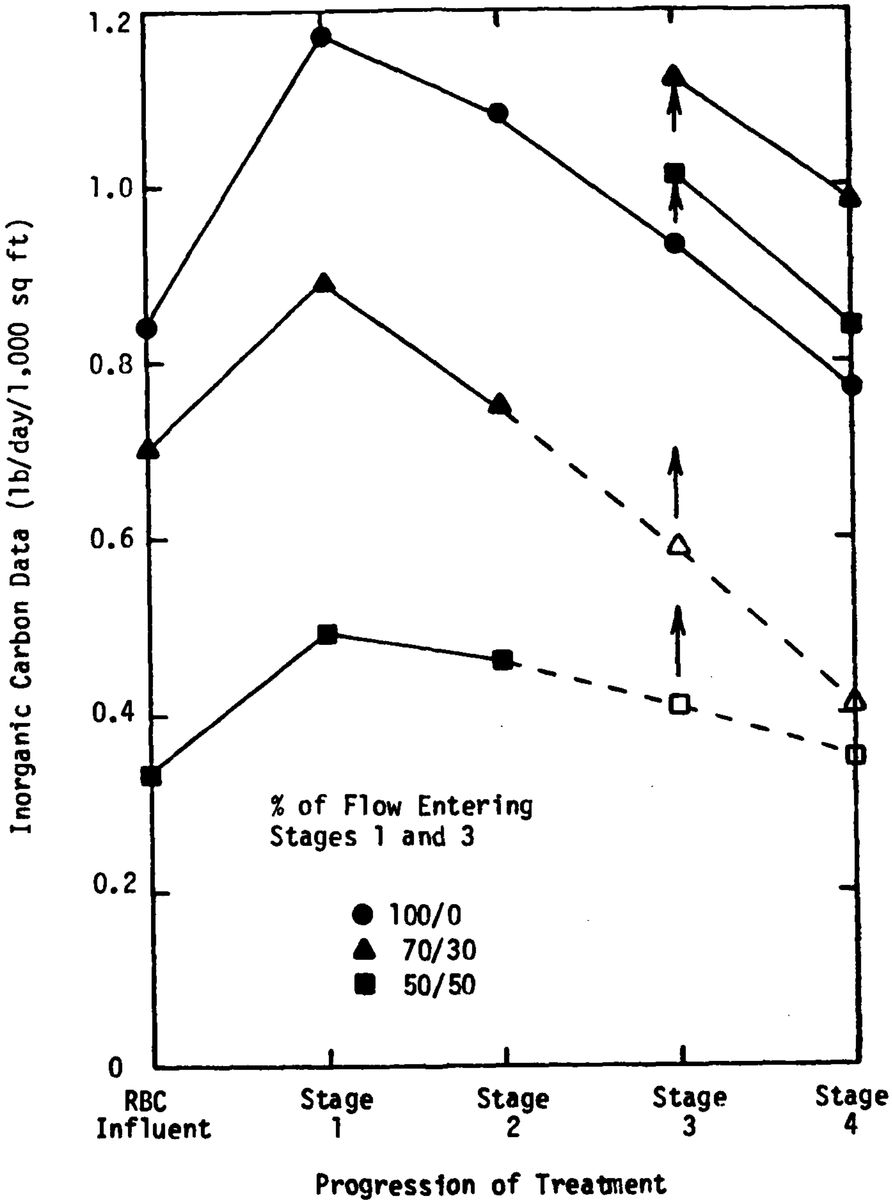

Figure 14. Inorganic Carbon Levels as a Function of the RBC Surface Area and Time, Indicating Relative Rates of Production and Removal. Open symbols are the expected values if additional wastewater had not been applied to stage 3.

TABLE 7. TOC AND pH VALUES CONCENTRATION WITHIN THE RBC STAGES[a]

Parameter	RBC Inf	Stage 1	Stage 2	Stage 3	Stage 4
TOC (mg/L)					
100/0	45	31	24	21	20
70/30	72	42	37	38	35
50/50	68	37	31	36	28
pH[b]					
100/0	9.1	8.9	8.6	8.2	7.9
70/30	9.3	8.8	8.3	8.4	8.0
50/50	9.5	8.7	8.1	8.3	7.7

a. The flow was split between stages 1 and 3 as indicated. The overall hydraulic loading was 2.5 gpd/sq ft.
b. Median value.

organic carbon applied to the third RBC stage was then converted to inorganic carbon, increasing the observed rate of pH depression in the latter stages. From these data, it can be concluded that flow splitting did allow for more efficient use of the RBC media surface area with respect to wastewater recarbonation.

CONCLUSIONS

In addition to the removal of phosphorus, lime pretreatment reduced the organic loading on the RBC process and allowed for recarbonation by microbial populations that produced carbon dioxide, thereby forming carbonate alkalinity necessary for nitrification after the initial BOD_5 has been removed. The resultant pH after recarbonation was also in the optimal range for nitrification. Nitrification was further enhanced since the availability of the RBC media surface area for nitrifying organisms increased as the surface area requirements for heterotrophic organisms declined with decreased BOD_5 loading.

Under conditions where the wastewater influent was split between RBC stages 1 and 3, comparable rates of nutrient removal as well as overall recarbonation were observed. Other conclusions are as follows:

1. Phosphorus levels in the secondary effluent of 2.0 mg/L (as P) or less are attainable by combining low-level lime addition with biological treatment processes.

2. The RBC process can recarbonate a wastewater stream without deleterious effects to the microorganisms.

3. pH depression by the RBC process was decreased by increased flow rates from 2.0 to 4.0 gpd/sq ft.

4. Lime pretreatment allows for a decreased organic load on the biological treatment system.

5. The decreased organic load applied to the RBC as a result of lime pretreatment reduced RBC media surface area requirements for heterotrophic populations.

6. Biological oxidation of organics present in the high pH primary effluent produced an excellent environment for nitrification (low BOD, adequate alkalinity, pH between 7.0 and 8.0).

7. The application of high pH wastewater to the third RBC stage was not detrimental to the microorganisms or to the overall removal of nutrients.

RECOMMENDATIONS

In the course of this study, a technique was developed for precipitation of phosphorus at a pH of 9.5 in the primary clarifier, prior to secondary treatment followed by wastewater recarbonation with an RBC unit process. This technique has been demonstrated in a pilot-scale unit operating on domestic sewage from a family housing area at Ft. Detrick. Application of this phosphorus precipitation technique to a full-scale RBC wastewater treatment plant apparently has not been attempted. The results of CERL/USAMBRDL pilot studies indicate that the low-lime phosphorus removal technique is feasible and should offer many advantages in the satisfaction of Army pollution control needs.

The need exists to confirm these promising pilot research results on a larger scale. This need is prompted by the fact that phosphorus removal regulations exist in more than 20 states and have identified 11 military installa tions as needing some degree of phosphorus removal. Furthermore, 7 of these 11 installations have requirements for nitrogen removal. The CERL/USAMBRDL pilot studies have shown that the low-lime addition technique not only removes phosphorus, but also enhances nitrification processes by reducing the organic load applied to the secondary treatment unit. These benefits achieved through lime pretreatment must also be confirmed in full-scale process operation.

In summary, the low-lime phosphorus removal portion of the pilot wastewater treatment train was a relatively straightforward application of technology, whereas the use of RBCs following the low-lime treatment has not yet been demonstrated in full scale. Therefore, the need exists to demonstrate the effectiveness and operational simplicity of a full-scale RBC system for secondary treatment and wastewater recarbonation following low-lime precipitation of phosphorus.

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